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APPLICATION NUMBER: *60/480,341*
FILING DATE: *June 20, 2003*
RELATED PCT APPLICATION NUMBER: *PCT/US04/19590*

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PROVISIONAL APPLICATION FOR PATENT COVER SHEET

This is a request for filing a PROVISIONAL APPLICATION FOR PATENT under 37 CFR 1.53(c).

Express Mail Label No. EL022597571US — Docket No.: DREX-1002USP

INVENTOR(S)

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TITLE OF THE INVENTION (500 characters max)

VORTEX REACTOR AND METHOD OF USING IT

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ENCLOSED APPLICATION PARTS (check all that apply)

■ Specification Number of pages 17 — ☐ CD(s) Number ____

■ Drawing(s) Number of Sheets 4 — ☐ Other (specify)

☐ Application Data Sheet. see 37 CFR 1.76

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■ Applicant claims small entity status. See 37 CFR 1.27

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CERTIFICATE OF EXPRESS MAILING UNDER 37 CFR 1.10

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The invention was made by an agency of the United States Government or under contract with an agency of the United States Government.

☐ No

☐ Yes, the name of the U.S. Government agency and the Government contract number are ______________.

Respectfully submitted,

SIGNATURE Kevin J. Dunleavy

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Date June 20, 2003

Registration No. 32,024

Docket No.: **DREX-1002USP**

USE ONLY FOR FILING A PROVISIONAL APPLICATION FOR PATENT

17364 U.S. PTO

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PROVISIONAL APPLICATION COVER SHEET

ADDITIONAL PAGE

		Docket Number: DREX-1002USP
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VORTEX REACTOR AND METHOD OF USING IT

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to the provision of a fluidized bed with low-temperature plasma without the use of a grid, and to a method of using such a fluidized bed.

2. Description of the Related Technology

Improving the efficiency of the operation of a fluidized bed remains an important technological goal, owing to the significant economic benefits that result in almost every sector of the economy.

Physical processes which utilize fluidized beds include drying, mixing, granulation, coating, heating and cooling. All these processes take advantage of the excellent mixing capabilities of the fluidized bed. Good solids mixing gives rise to good heat transfer, temperature uniformity and ease of process control. One of the most important applications of the fluidized bed is to the drying of solids. Fluidized beds are currently used commercially for drying such materials as crushed minerals, sand, polymers, pharmaceuticals, fertilizers and crystalline products.

Fluidized beds are often used to cool particulate solids following a reaction. Cooling may be by fluidizing air alone or by the use of cooling water passing through tubes immersed in the bed

Other examples of the application of fluidized bed technology to different kinds of chemical reaction are ethylene hydrogenation, sulfide ore roasting, combustion, and hydrocarbon cracking. Reasons for using fluidized beds are the substantially uniform temperature inside the bed, ease of solid handling, and good heat transfer that they provide.

A new approach to the production of Vinyl Acetate Monomer (VAM) is to use a fluidized-bed process in which gas phase reactants are contacted continuously over (small-sized) supported catalytic particles under fluidized conditions.

Fluidized beds are also used as sorters in the food processing industry. This technology uses a mobile field separation apparatus that has a dry fluidized bed system with sand as the fluidized medium. The technology can remove all dirt clumps from the lifted product stream, such as from potatoes. The technology could be applied to cleaning field tare from incoming raw food product streams and could be used by industrial processors to replace water flumes that consume significant electrical power and water and require a relatively high degree of maintenance.

Fluidized beds can also be used in gasification systems. The fluid bed converts, for example, biomass waste products into a combustible gas that can be fired in a boiler, kiln, gas turbine or other similar device as a means to convert a portion of the fuel supply to clean, renewable biomass fuel. Gasification is the thermal decomposition of organic matter in an oxygen deficient atmosphere producing a gas composition containing combustible gases, liquids and tars, charcoal, and air, or inert fluidizing gases. Typically, the term "gasification" refers to the production of gaseous components.

A gas distributor is a device designed to ensure that the fluidizing gas is always substantially evenly distributed across the cross-section of the bed. It is an important part of the design of a fluidized bed system. Good design is based on achieving a pressure drop which is a sufficient fraction of the bed pressure drop. Some distributor designs in common use are (a) drilled plate, (b) cap design, (c) continuous horizontal slots, (d) stand pipe design, and (e) sparge tubes with holes pointing downwards.

Loss of fluidizing gas will lead to collapse of the fluidized bed into a packed bed. If the process involves the generation of heat, then this heat will not be dissipated as well from the packed bed as it was from the fluidized bed.

All parts of the fluidized bed unit are subject to erosion by the solid particles.

Heat transfer tubes within the bed or freeboard are particularly at risk and erosion here may lead to tube failure. Erosion of the distributor may lead to poor fluidization and areas of the bed becoming deaerated. Loss of fine solids from the bed reduces the quality of fluidization and reduces the area of contact between the solids and the gas in the process. In a catalytic process this generally results in lower conversion.

In addition, reactors employing a grid for the generation of plasma are also subject to erosion by contact with solid particulates. Also, generation of plasma using a grid is less energy efficient than other methods of plasma generation.

In a fluidized bed combustion chamber, known as a spouted bed reactor, a cone shaped hopper is continuously fed with solid particles. The solid particles are suspended briefly and processed in an axial flow of gas originating from the bottom or apex of the cone. One disadvantage of the spouted bed reactor is the instability of the axial gas flow. The solid particles fall out of suspension easily due to turbulence and accumulate in the narrower bottom portion of the cone. In addition, the bottom entry tube provides only an axial gas flow velocity component. Thus, there is no orthogonal gas flow velocity component to assist in distributing the solid particles throughout the cone shaped reactor. Consequently, the mixing of solid particles with gas, and the interaction among the solid particles, are relatively poor. The poor mixing and non-uniform particle distribution result in a relatively low efficiency of combustion and/or gasification.

In order to improve the distribution of solid particulates throughout a cone shaped reactor and, thereby, minimize inefficiencies produced by non-ideal particle distributions, it is known to utilize a circumferential flow of gas whose direction is orthogonal to the axial gas flow. The axial and circumferential gas flows may preferably be adjusted to produce a vortex in the conical reactor.

U.S. Patent No. 5,486,269, for example, describes an inverted conical reactor, suitable for coal gasification, which uses a tangential flow of air to achieve a vortex flow pattern.

None of these devices and methods, however, provides fluidization of solid particulates with optional plasma energy input and without employing a grid. Therefore, there remains a need for a fluidization reactor with optional plasma energy input that does not employ a grid.

SUMMARY OF THE INVENTION

Accordingly, it is an object of certain embodiments of the invention to provide a fluidization reactor with optional plasma energy input, that does not employ a grid.

In order to achieve the above and other objects of the invention, a vortex reactor is provided. In one aspect of the invention, the vortex reactor has a reaction chamber including a substantially frustum-shaped portion. The narrower part of the frustrum-shaped portion is downwardly oriented. The vortex reactor is further equipped with a device for creating an axial gas flow, and a device for creating a circumferential gas flow. Also included is a solid particle inlet for introducing particulate solids into the reactor.

In another aspect of the invention, a method for plasma-assisted processing of a solid particulate is provided. In this method, a vortex reactor is provided which includes a substantially frustum-shaped portion. The reactor is provided with a circumferential gas flow and, optionally, with an axial gas flow. Solid particles are added to the reactor, and the particles are processed by reaction with at least one of the gases. The treatment of solid particulates may optionally be assisted by generating plasma in at least a portion of the reaction mixture.

These and various other advantages and features of novelty that characterize the invention are pointed out with particularity in the claims annexed hereto and forming a part hereof. However, for a better understanding of the invention, its advantages, and the objects obtained by its use, reference should be made to the drawings which form a further part hereof, and to the accompanying descriptive matter, in which there is illustrated and described a preferred embodiment of the invention.

BRIEF DESCRIPTION OF THE DRAWINGS

FIGURE 1 is a cross-sectional view of one embodiment of a vortex spouted bed reactor.

FIGURE 2 is a cross-sectional view of a vortex spouted bed reactor taken along line II-II of Figure 1, showing a nozzle arrangement.

FIGURE 3 is a cross-sectional view of another embodiment of a vortex reactor equipped for plasma generation.

FIGURE 4 is a cross-sectional view of a yet another embodiment of a vortex reactor equipped for plasma generation.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Several patents are referenced herein in order to illustrate the contents of the art. Each of these patents is incorporated by reference as if set forth fully herein.

In general, dimensions, sizes, tolerances, parameters, shapes and other quantities and characteristics are not and need not be exact, but may be approximate and/or larger or smaller, as desired, reflecting tolerances, conversion factors, rounding off, measurement error and the like, and other factors known to those of skill in the art. In general, a dimension, size, parameter, shape or other quantity or characteristic is "about" or "approximate" as used herein, whether or not expressly stated to be such.

Referring now to the drawings, wherein like reference numerals designate corresponding structure throughout the views, and referring in particular to FIGURE 1, an embodiment of a vortex spouted bed reactor 500 of the present invention is depicted. The vortex spouted bed reactor 500 includes a reaction chamber 10 formed by a hollow frustum-shaped portion 20. The narrower part 30 of the frustum-shaped portion 20 is downwardly oriented. A bottom entry tube 35 connects to the narrower part 30. The frustum-shaped portion 20 has a top portion 40, to which a reaction chamber extension 50 is optionally attached. The vortex spouted bed reactor 500 may

optionally include a cap 55. At or near the top of the vortex spouted bed reactor 500, there is a particle feeder 90, for introducing solid particles 80 into the reaction chamber 10. An outlet 100 for ash and exhaust gas is also positioned at or near the top of the vortex spouted bed reactor 500. One or more additional vortex flow nozzles 120 may also be located within the reaction chamber 10.

In the embodiment shown in FIGURE 1, a circumferential gas flow in the reaction chamber 10 is produced by introducing a tangential gas flow 65 tangential to the walls of the bottom entry tube 35 and the frustum-shaped portion 20. The tangential gas flow 65 is created by gas flow 32 entering reaction chamber 10 through one or more nozzles 60 located proximate to the narrower part 30 of the frustum-shaped portion 20. The circumferential gas flow produced in the reaction chamber becomes a vortex gas flow 38 when combined with an axial flow of gas 33 from bottom entry tube 35 which flows through the porous bed 70. The vortex gas flow 38 is characterized by an intense swirl or spiral flow with a relatively strong circumferential component. The solid particles 80 can thus be spread throughout the reaction chamber 10 and over the sidewalls of the frustum-shaped portion 20. The porous bed 70 located at or near the narrower part 30 also functions to retain the solid particles 80 in the reactor 500, should they fall from the vortex gas flow 38. The axial gas flow 33 can also help to recirculate fallen solid particles 80 in the reaction chamber 10, thus improving particle interaction, the uniformity of particle distribution, and reactor efficiency.

Reverse vortex flow nozzles 120 may advantageously be included in the vortex spouted bed reactor 500. The reverse vortex flow nozzles 120 are preferably located proximate to the top of the reactor 500. The reverse vortex flow nozzles 120 are positioned to create a reverse vortex flow 39 that moves in the same direction as the vortex gas flow 38 generated by a combination of the tangential gas flow 65 and the axial gas flow 33. This reverse vortex flow 39 helps particles 80 to be recirculated within the reaction chamber 10.

Furthermore, the vortex spouted bed reactor 500 of the invention advantageously provides more effective interaction among solid particles 80, gas, , and plasma during fluidzation processes. This interaction includes a high degree of mixing among the gas and particles, thus increasing the yield of the chemical reactions. Processes conducted in reactor 500 are also characterized by increased effective diameter of gas, and and/or plasma in the reaction chamber 10.

Suitable gases for use in the reactor of the present invention include, without limitation, air, oxygen, nitrogen, steam, hydrogen, lower hydrocarbons, or mixtures of one or more thereof, for example a mixture of steam and a lower hydrocarbon. In general, a gas is suitable for use in the reactor of the present invention if it comprises a reagent, participates in the fluidization, or if it is inert but can feasibly support a plasma or otherwise transfer energy to the reaction mixture.

FIGURE 2 depicts a cross-sectional view of a multiple nozzle arrangement, wherein gas enters the vortex spouted bed reactor 500 tangentially at 65 through four nozzles 60, thereby creating a gas flow tangential to the walls of the bottom entry tube 35 that contributes to providing a vortex gas flow 38 in the reaction chamber 10. The vortex gas flow 38 gradually moves upward in the reaction chamber 10 with a strong circumferential velocity component. In order to evenly distribute the gas into multiple nozzles 60, a gas passage 130 may be used. The number of nozzles 60 employed in a particular reactor is preferably no more than 8, and more preferably, four nozzles 60 are employed.

The multiple nozzle arrangement shown here produces a swirl flow inside the reactor. Any other device that can generate the swirl flow inside the reactor can be used. For example, multiple vanes and a spiral shaped passage can also generate a swirl flow inside the reactor,

Advantageously, the porous bed 70 of the vortex spouted bed reactor 500 shown in FIGURE 1 may be replaced with a flow restrictor 150 that reduces the effective diameter of the bottom entry tube 35 to help retain the solid particles 80 within the reaction chamber 10, and permit sufficient axial gas flow 33 from the

bottom entry tube 35 to the reaction chamber 10. For example, referring to FIGURE 3, a flow restrictor 150, shown in vertical cross-section, is located in the center of the bottom entry tube 35 of vortex reactor 600. In the embodiment shown in FIGURE 3, the flow restrictor 150 is biconical, and thus diamond-shaped, as viewed in a vertical cross-section. The base or horizontal cross-section of the widest portion of the flow restrictor 150 is preferably circular when the flow restrictor 150 is located in a circular bottom entry tube 35, to provide a uniform gap 140 between the flow restrictor 150 and the wall of the bottom entry tube. Similarly, if the bottom entry tube 35 has a square cross-section, the horizontal cross-section of the widest portion of the flow restrictor 150 is preferably square to again maintain a substantially uniform size of the gap 140 between the flow restrictor 150 and the walls of the bottom entry tube 35. The flow restrictor 150 may also be located in the reaction chamber 10, or partially in the reaction chamber 10 and partially in the bottom entry tube 35.

Still referring to FIGURE 3, multiple nozzles 60 may be positioned such that the vortex gas flow 38 is created below the gap 140 for improved acceleration of the gas. Improved acceleration of the gas is obtained by forcing the gas of the vortex gas flow to pass through the relatively narrow gap 140 between the flow restrictor 150 and the walls of the bottom entry tube 35, thereby accelerating the gas.

The flow restrictor 150 may have any shape that is suitable for reducing the effective diameter of the bottom entry tube 135, while permitting at least axial gas flow 33 past or through flow restrictor 150. Many such objects are conventional in the field of fluid mechanics, including, without limitation, conical and biconical objects that create Venturi flow; spheres; and truncated biconical objects that are trapezoidal, as viewed in a vertical cross-section.

Non-equilibrium low-temperature plasma reactions are a highly efficient method for processing solid particles. Accordingly, FIGURE 3 presents an embodiment of a vortex reactor 600 in which the vortex reactor 600 is equipped to generate plasma to assist in improving fluidized bed processing. Flow restrictor 150 functions as a first electrode, and the sidewall of the frustum-shaped portion 20

functions as a second electrode. Voltage is applied from an external source, not shown, to the first and second electrodes to create a voltage difference between the first and second electrodes. A sufficient voltage difference between the first and second electrodes will cause an electrical arc 170 to span the distance between the first and second electrodes. Gas that comes in contact with the arc 170 may become ionized to form plasma. It is well understood that the voltage difference required to generate the arc will depend on the distance between the first and second electrodes, and on the concentration and nature of the matter in the reaction chamber 10.

Preferably, for better performance, the vortex reactor 600 is designed to provide a gliding arc in the reaction chamber 10. For this purpose, the flow restrictor 150, which functions as the first electrode, can be extended using a straight rod 160 in order to spread the electrical arc 170 upward as well as along the circumferential direction through the reaction chamber 10 as shown in FIGURE 3. In this manner, a gliding arc can be created in the reaction chamber 10.

In general, the provision of a small gap 140 between the flow restrictor 150, acting as the first electrode, and the sidewalls of the bottom entry tube 35 or frustum-shaped portion 20 to initiate the electrical arc 170, combined with a gradual increase in the size of the gap between the first and second electrodes, is required to provide the desired gliding arc. Accordingly, flow restrictors of any suitable geometry and size can be employed as the first electrode to provide the desired gliding arc, as long as they provide the small gap 140 and a gradual increase in the size of the gap.

FIGURE 3 also depicts the initiation point 180 and termination point 190 of a gliding arc that is produced between the first and second electrodes when the vortex reactor 600 is optionally equipped for plasma generation. The gap 140 is made small, for example, about 3 mm, so that an electrical arc 170 can be initiated at initiation point 180 with a voltage of about 10 KV DC power. The distance between the first and second electrodes should increase gradually so that the electrical arc 170 can glide upwardly in the reaction chamber 10 to cover at least a substantial portion of the reaction chamber 10, and more preferably all of the reaction chamber 10. As a result

of the distance between the first and second electrodes increasing, the electrical arc 170 eventually terminates at a termination point 190 when the distance becomes too great for the electrical arc 170 to cross the gap between the first and second electrodes. In this manner, a low-temperature, non-equilibrium plasma reaction can be created in the reaction chamber 10. This provides an efficient processing method for solid particles.

Referring to FIGURE 4, there is shown another alternative embodiment of a vortex reactor 600 wherein the flow restrictor 152 includes one or more channels 154 in the flow restrictor 152. Each channel is preferably oriented in a substantially axial direction, relative to the bottom entry tube 35, as shown in FIGURE 4. Channels 154 may be used to increase axial and/or circumferential gas flow, or to alter the ratio of axial to circumferential flow. Channels 154 may have a substantially constant diameter or, in a more preferred embodiment as shown in FIGURE 4, channels 154 may taper in the axial direction from a larger diameter at the inlet side 156 of the channels 154 to a smaller diameter at the outlet side 158 of the channels 154 to thereby provide additional acceleration of the gases flowing through channels 154.

Also shown in FIGURE 4 is an electrical input 162 connected to the flow restrictor 152 for applying a voltage to the flow restrictor 152 for plasma generation. A similar electrical connection 164 is provided for applying a voltage to the wall of the frustum-shaped portion 20, as shown. The flow restrictor 152 of FIGURE 4 represents an alternative preferred flow restrictor which has a trapezoidal shape, as viewed in a vertical cross-section. One advantage of the trapezoidal flow restrictor 152 is that it can provide a very gradual widening of the gap 140 between the flow restrictor 152 and the walls of the bottom entry tube 35 and frustum-shaped portion 20. Also, the entire vertical length of the trapezoidal flow restrictor 152 can be employed to gradually widen the gap 140, whereas in the case of the diamond-shaped flow restrictor 150 of FIGURE 1, only half of the vertical length of the flow restrictor 150 is employed to gradually widen the gap 140.

It is to be understood that various features of the different embodiments shown in the drawings may be combined with one another in a vortex reaction in accordance with the present invention. For example, flow deflector 110 can be employed in any of the embodiments, various flow restrictors 150, 152 can be interchanged, optional plasma generation can be used in any of the various reactor configurations, reverse vortex flow nozzles 120 may be employed in any of the various reactor configurations, etc.

Materials and specifications suitable for constructing a vortex reactor in accordance with the present invention are well known to those of skill in the art. The current strength should be less than 100 Amps and the voltage applied between the two electrodes should be about 10 KV. The cone angle of the frustum-shaped reactor, which is the angle between a vertical line and the wall of the inclined reactor should be in a range of 5 to 45 degrees, when the frustum-shaped reactor is upright.

In a second aspect, the present invention relates to a method for the processing of solid particulates in a vortex reactor. The method includes the steps of introducing solid particles into said reaction chamber, subjecting said solid particles to a vortex gas flow created by a combination of a circumferential gas flow and an axial gas flow, and processing said solid particles by drying, mixing, coating, heating, peeling, or chemical reaction.

In the method, the axial gas flow may be created by the steps of feeding gas in an axial direction into said reaction chamber and accelerating said axial gas flow through a flow restriction. The circumferential gas flow may be created by the step of feeding gas into said reaction chamber in a direction tangential to a sidewall of said reaction chamber, or alternatively, when the vortex reactor includes a bottom entry tube, by feeding gas into said bottom entry tube in a direction tangential to a sidewall of said bottom entry tube at a location below the flow restriction.

The method may further include the step of generating plasma in said reaction chamber. The step of generating plasma in said reaction chamber may include the step of providing a gliding electrical arc in said reaction chamber, as discussed above.

A reverse vortex flow, as discussed above, may also be provided in the method of the present invention.

It is to be understood that even though numerous characteristics and advantages of the present invention have been set forth in the foregoing description, together with details of the structure and function of the invention, the disclosure is illustrative only, and changes may be made in detail, especially in matters of shape, size and arrangement of parts within the principles of the invention to the full extent indicated by the broad general meaning of the terms in which the appended claims are expressed.

WHAT IS CLAIMED IS:

1. A vortex reactor, comprising
a substantially frustum-shaped portion forming a reaction chamber therein, said frustum-shaped portion having a narrower part that is downwardly oriented;
an axial flow apparatus fluidly connected to the reaction chamber for creating an axial gas flow in said reaction chamber;
a circumferential flow apparatus fluidly connected to the reaction chamber for creating a circumferential gas flow in said reaction chamber; and
a solid particulate inlet connected to said reaction chamber.

2. The vortex reactor of claim 1, wherein said axial flow apparatus comprises a gas supply and an apparatus selected from the group consisting of a porous bed and a flow restrictor.

3. The vortex reactor of claim 2, wherein said flow restrictor further comprises at least one channel therein which provides a fluid connection between said gas supply and said reaction chamber.

4. The vortex reactor of claim 3, wherein said circumferential flow apparatus is located below said flow restrictor.

5. The vortex reactor of claim 4, wherein the cross-sectional area of said at least one channel tapers from a first, cross-sectional area at an end of the channel that is fluidly connected to said gas supply, to a smaller, second, cross-sectional area at an end of the channel that is fluidly connected to the reaction chamber.

6. The vortex reactor of claim 1, wherein said apparatus for creating circumferential gas flow comprises a gas supply and one or more gas inlet nozzles oriented tangentially relative to a sidewall of the narrower part of said frustum-shaped portion.

7. The vortex reactor of claim 1, wherein said reactor further comprises a bottom entry tube fluidly connected to said reaction chamber at the narrower part of said frustum-shaped portion, and said apparatus for creating circumferential gas flow comprises a gas supply and one or more gas inlet nozzles oriented tangentially relative to a sidewall of the bottom entry tube.

8. The vortex reactor of claim 2, further comprising apparatus for generating plasma.

9. The vortex reactor of claim 8, comprising a flow restrictor which functions as a first electrode for plasma generation, wherein a sidewall of said frustum-shaped portion functions as a second electrode for plasma generation, and wherein said apparatus for generating plasma comprises an apparatus for applying a first voltage to said first electrode and an apparatus for applying a second, different voltage to said second electrode.

10. The vortex reactor of claim 9, wherein said flow restrictor is positioned to provide a small gap between said first and second electrodes for initiation of a plasma generating electrical arc at said small gap, and said flow restrictor is shaped to provide a gradual increase in the size of said gap between said first and second electrodes in an upward direction to provide a gliding arc in said reaction chamber.

11. A vortex reactor as claimed in claim 10, further comprising at least one flow restrictor located in an upper central portion of said reaction chamber for the purpose of impeding downward flow of gas in a central portion of said reaction chamber.

12. A method for fluidization treatment of solid particles, comprising the steps of providing a vortex reactor, said vortex reactor comprising:

a substantially frustum-shaped portion forming a reaction chamber therein, said frustum-shaped portion having a narrower part that is downwardly oriented, and an upper portion,

an axial flow apparatus fluidly connected to the reaction chamber for creating an axial gas flow in said reaction chamber,

a circumferential flow apparatus fluidly connected to the reaction chamber for creating a circumferential gas flow in said reaction chamber, and

a particulate solids inlet connected to said reaction chamber;

introducing solid particles into said reaction chamber;

subjecting said solid particles to a vortex gas flow created by a combination of a circumferential gas flow and an axial gas flow; and processing said solid particles.

13. The method of claim 12, wherein said axial gas flow is created by the steps of feeding gas in an axial direction into said reaction chamber and accelerating said axial gas flow through a flow restriction.

14. The method of claim 13, wherein said circumferential gas flow is created by the step of feeding gas into said reaction chamber in a direction tangential to a sidewall of said reaction chamber.

15. The method of claim 13, wherein said vortex reactor further comprises a bottom entry tube, said flow restriction is located in said bottom entry tube and said circumferential gas flow is created by the step of feeding gas into said bottom entry tube in a direction tangential to a sidewall of said bottom entry tube at a location below said flow restriction.

16. The method of claim 15, further comprising the step of generating plasma in said reaction chamber.

17. The method of claim 16, wherein the step of generating plasma in said reaction chamber comprises the step of providing a gliding electrical arc in said reaction chamber.

ABSTRACT OF THE DISCLOSURE

A vortex reactor is provided. The vortex reactor includes a reaction chamber formed by a frustum-shaped portion, the narrower part of which is downwardly oriented. Proximate to the narrower part of the frustum-shaped portion, the vortex reactor includes apparatus for creating an axial gas flow and apparatus for creating a circumferential gas flow. The vortex reactor also includes a particulate solid inlet for feeding particulate solids to the reaction chamber. The vortex reactor may optionally include apparatus for generating plasma in the reaction chamber by providing a gliding arc electrical discharge in the reaction chamber. Also provided is a method of processing particulate solids using the vortex reactor of the invention.

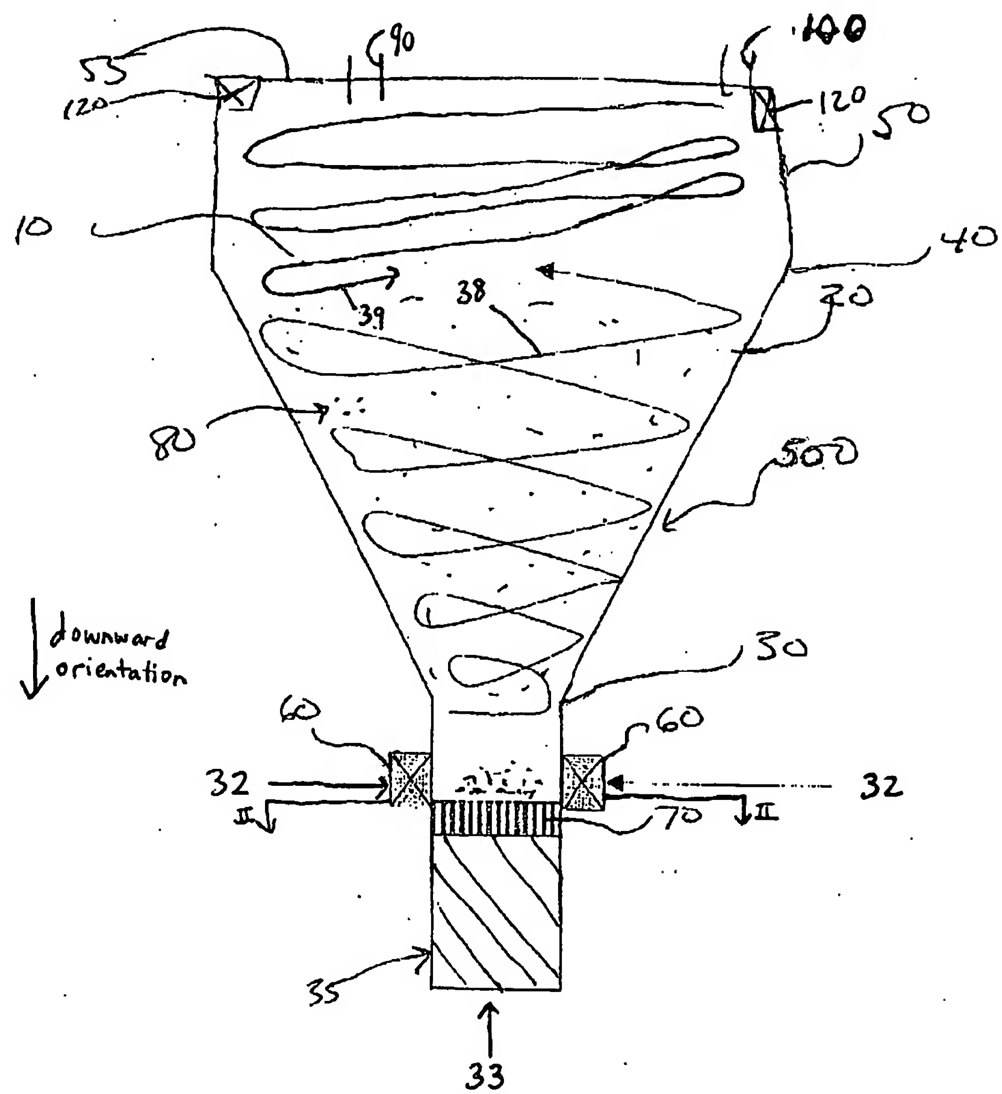

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FIG. 1

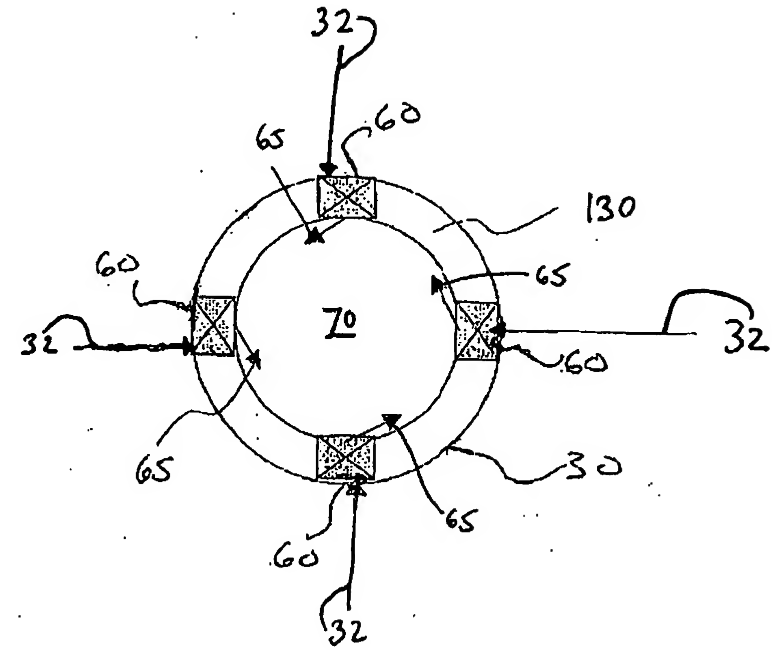

FIG. 2

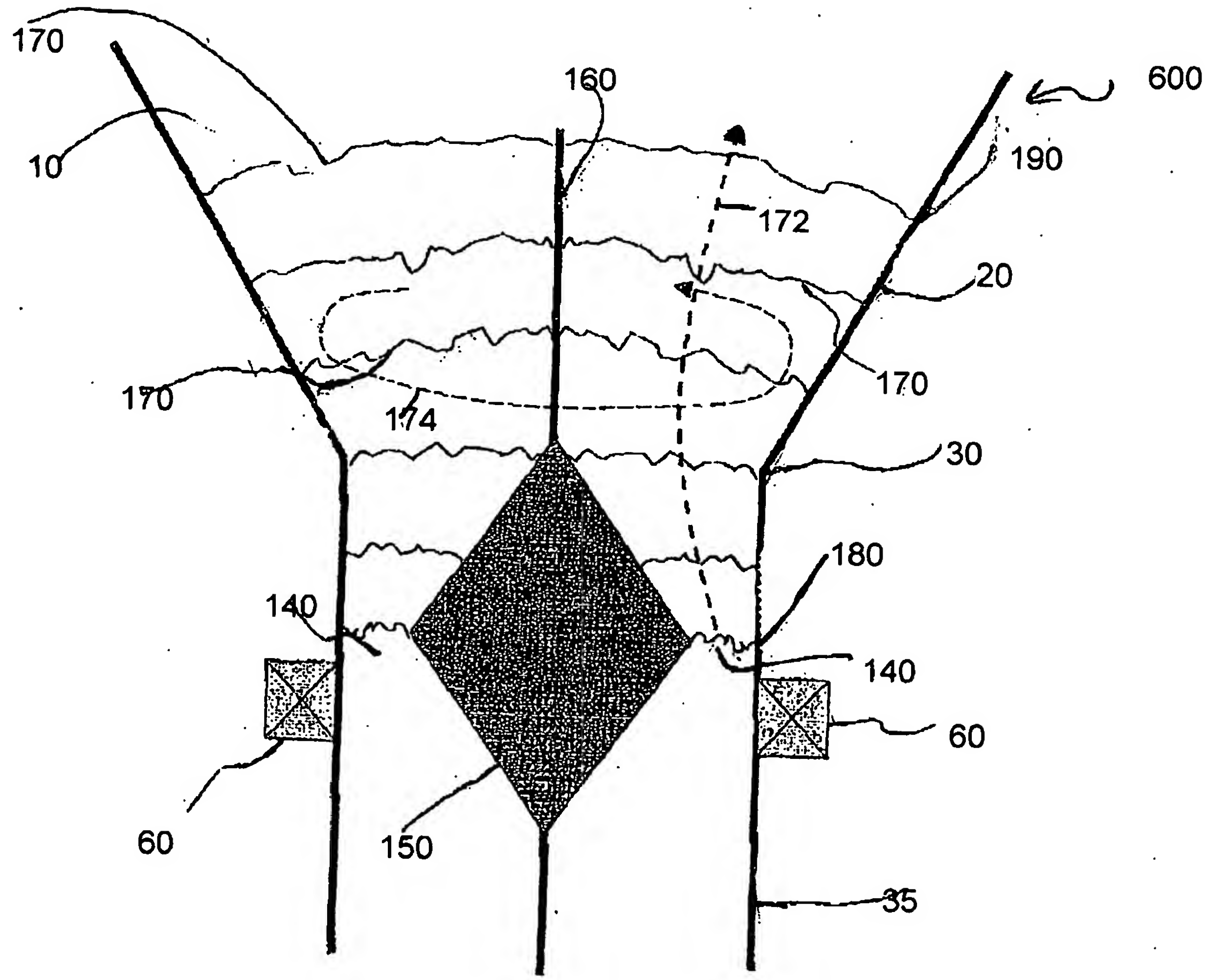

FIGURE 3

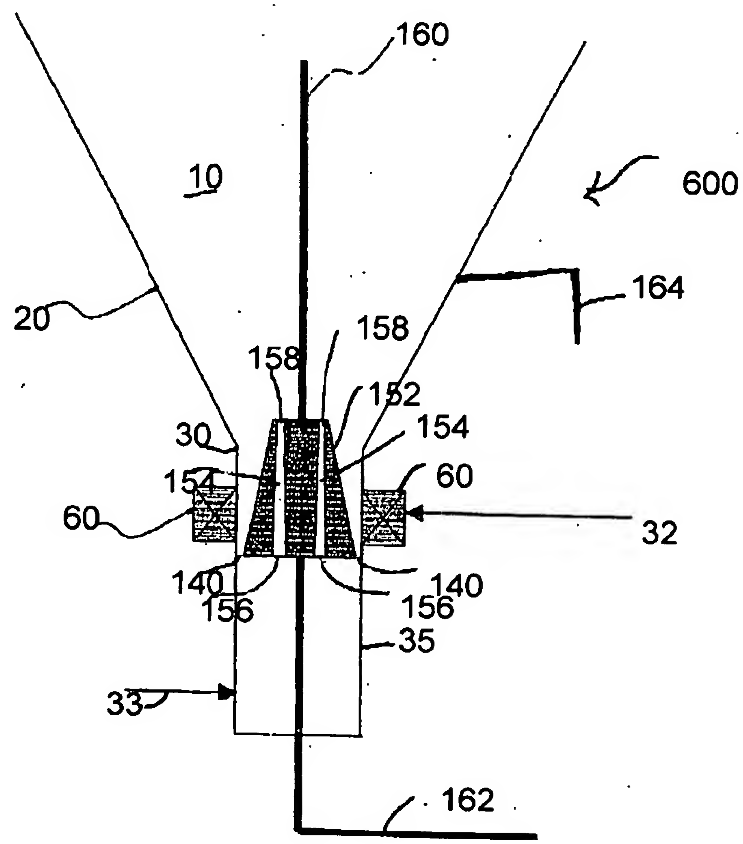
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Figure 4